SYSTEM AND METHOD FOR SUPPRESSION OF WAFER TEMPERATURE DRIFT IN COLD-WALL CVD SYSTEMS

FIELD OF THE INVENTION

The present invention relates to the field of semiconductor wafer manufacturing. More particularly, the invention relates to a method and system for controlling and/or compensating for varying wafer temperature during non-selective epitaxial growth.

BACKGROUND OF THE INVENTION

5   Epitaxy is used in the semiconductor industry to grow a layer of semiconductor material on top of a single-crystalline semiconductor substrate in such a way that the crystal lattice is maintained. Common examples are the growth of an epitaxial silicon layer on top of a silicon substrate

10   or the growth of a SiGe alloy layer on top of a silicon substrate. This can be done by chemical vapor deposition (CVD) in a proper environment. The wafer is heated to a suitable temperature and gases containing the required components are passed over the substrate, which usually is a

15   silicon wafer. To avoid growth on the walls of the reactor

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vessel it is advantageous to heat just the wafer and to keep the reactor walls at a relatively low temperature.

Common epitaxial reactors used in the semiconductor

5   industry consist of a transparent quartz reactor chamber through which the gas is passed. Inside the quartz chamber the substrate is located on top of a susceptor. The wafer and susceptor are irradiated by high intensity lamps and heated to the desired temperature. As the quartz walls of the

10   reactor chamber absorb comparatively little radiation they can easily be cooled. The temperature of the susceptor is measured and controlled; it is assumed that the wafer has approximately the same temperature as the susceptor.

15   Figs. 1a and 1b illustrate a simple case. A susceptor

.   10, usually a graphite disk with a SiC coating, has a pocket 11 machined in its top surface to hold a wafer (not shown). The temperature of the susceptor 10 is measured by a pyrometer 12 aimed at the backside of the susceptor 10. The

20   pyrometer can also be aimed at the top surface of the wafer, directly measuring the wafer temperature. However, since the emissivity of the wafer surface is not constant, especially when patterned wafers have to be deposited, this is not a good method to measure the wafer temperature. In order to

improve the uniformity of the deposited layer the susceptor
10 can rotate during the deposition process.

Figs. 2a, 2b and 2c show a more complicated case. A
5   susceptor 20 consists of two parts: a rotating inner part 21
and a stationary outer part 22 as shown in Fig. 2a. The
rotating inner part 21 holds a wafer (not shown) in a pocket
23 and rotates. The stationary outer part 22 (e.g., a ring)
of the susceptor 20 is made of the same material as the
10 rotating inner part 21, but does not rotate. This is done to
enable a temperature measurement to be done with thermocouple
28 (shown in cross section in Fig.2c).

A small pocket 25 centered at the backside of the
15 susceptor 20 (shown in cross section in Fig. 2b) is intended
to receive the tip of the thermocouple 24 as shown in Fig.
2c. The thermocouple 24 rotates together with the rotating
inner part 21. The stationary outer part 22 holds one or more
thermocouples 28 via a thermocouple bore 26 to measure the
20 temperature at the wafer edge. All the thermocouples 24 and
28 are tied to a temperature control system 27 allowing for a
very accurate control of the temperature at the center and
the edge of the susceptor 20.

While these arrangements have proven useful, significant shortcomings exist with these arrangements.

SUMMARY OF THE INVENTION

5   The Applicant of the present invention has realized that there are several significant shortcomings of the conventional systems discussed above. As discussed more below, there is a problem caused by varying wafer temperature during non-selective epitaxial and poly-silicon growth on
10   patterned wafers at low temperatures and reduced pressure.

One aspect of the present invention is directed to a method and apparatus that uses one or more optical fibers in a susceptor that monitor radiation emitted by the backside of
15   the wafer. There are several benefits of this type of configuration, e.g.:

      (1)   the quality of epi layers improves because dopant and Ge levels are more stable throughout the layer of a wafer; and

20   (2)   tuning efforts to grow a specific layer or layer sequence in a wafer can be significantly reduced.

One embodiment of the present invention is directed to a wafer manufacturing apparatus including a susceptor including

a support for a wafer, at least one optical fiber connected to the susceptor so that radiation from a bottom side of the wafer can be monitored, and an optical signal measurer coupled to the at least one optical fiber.

Another embodiment of the present invention is directed to a method for manufacturing a wafer using an expitaxy process. The method includes the steps of receiving an optical radiation signal from a backside of a wafer, filtering out a spectrum of the radiation signal for which the wafer is opaque and converting the filtered radiation signal into an electrical signal. The method also includes the step of controlling a wafer temperature by keeping the electrical signal constant during a deposition cycle.

Yet another embodiment of the present invention is directed to a method to decrease temperature differences between wafers with different patterns or different thickness of the field oxide or nitride in epitaxial reactors. The method includes the steps of heating a wafer to a deposition temperature at a first pressure, registering a first radiation signal level from a backside of the wafer and during a subsequent deposition cycle at a second pressure that is less than the first atmospheric pressure, controlling a temperature so that a second radiation signal level from

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the backside of the wafer is substantially equal to the

registered first radiation signal level.

This brief summary has been provided so that the nature

of the invention may be understood quickly. A more complete

understanding of the invention can be obtained by reference

5   to the following detailed description of the preferred

embodiments thereof in connection with the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

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Fig. 1 depicts a prior art susceptor in an epitaxial

reactor.

Fig. 2 depicts another prior art susceptor in an

15   epitaxial reactor.

Fig. 3 depicts a susceptor in accordance with a

preferred embodiment of the present invention.

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DETAILED DESCRIPTION

The assumption that a wafer is at approximately the same
temperature as a susceptor is sufficiently close to reality
at high temperatures. In this regard, high temperatures
being defined as a temperature regime in which the growth

5   rate is "transport limited." The diffusion of fresh
reactants to the surface of the wafer is the limiting factor
and in this regime the growth rate is only moderately
dependent on the temperature at high temperatures. Above 850-
900°C in case of silicon epitaxy, the systems described above

10   may provide satisfactory results. However, at low
temperatures this is no longer the case. There are two
reasons why the susceptor temperature is an insufficient
measure of the wafer temperature in the low-temperature
range. In this regard, low-temperatures being defined as a

15   temperature regime in which the growth rate is not "transport
limited."

First, it is noted that at low-temperatures, the growth
rate of the wafer now is a strong function of the

20   temperature. At low temperatures, for silicon epi below
850°C, the growth rate is determined by the reaction rate.
The growth is said to be in the "kinetically controlled"
regime, characterized by a strong temperature dependency. In
this case, a temperature difference between the wafer and

susceptor is much more noticeable at low temperature than it
is at high temperature.

5   Next it is noted that at lower temperatures, the heat
transfer between the wafer and susceptor shifts from being
dominated by radiation to being dominated by conduction. A
thin gas film formed between the susceptor and the wafer can
play an important role and the heat transfer decreases when
the pressure is reduced. This implies that there can be a
10   substantial temperature difference between the wafer and the
susceptor at low temperatures and at reduced pressure.

As discussed in the "Emissivity Effects in Low-
Temperature Epitaxial Growth of Si and SiGe", W.B.de Boer et
15   al., Electrochemical Society Proceedings Vol. 99-10,
incorporated herein by reference, the temperature difference
(between the wafer and the susceptor) is not the major
problem. The problem is that during the growth on patterned
wafers, the emissivity of the wafer changes. This changes
20   the heat flux between wafer and susceptor, which in turn
causes the wafer temperature to change during the growth.
This rather unpredictable temperature drift may cause one or
more harmful effects:

i)   the growth rate changes during the deposition,
the layer thickness of the wafer does not increase
linearly with the deposition time;

ii)   the incorporation of, e.g., B and P is not
constant and changes during the deposition;

iii)   when growing SiGe alloy layers, the Ge content
varies during the deposition; and

iv)   when switching to a different pattern or a
different thickness of field oxide or nitride, the wafer
temperature can be different and one has to go through
an elaborate retuning procedure.

The varying emissivity of the wafer and the more
constant emissivity of the susceptor edge around the wafer
also causes a center-to-edge effect on the wafer. The
temperature at the center changes differently from the
temperature at the edge of the wafer during the growing
cycle, i.e., the center-to-edge variation of the layer
thickness and dopant concentration changes with increasing
layer thickness and changes with the pattern.

The problems described here are characteristic of so-
called cold-wall reactors and are irrespective of the heating
method. In this regard, due to the high temperature
dependency of the growth rate and of parameters like B and Ge

incorporation into the growing layers, the problems manifest themselves, for example, when blanket layers are grown on patterned wafers at low temperature and reduced pressure. During the blanket deposition of silicon, an epitaxial layer

5   is deposited in windows where underlying silicon is exposed and a poly-silicon (or poly-SiGe) layer is deposited on top of the oxide or nitride. It is the growth on top of the oxide and/or nitride layers usually covering more than 90% of the wafer surface, which changes the emissivity of the wafer,

10   resulting in temperature variations.

One possible method to address the problem described above would be to measure the true wafer temperature, e.g. with a pyrometer aimed through the quartz reactor wall at the

15   wafer with proper optics. However, this has not been possible in the present generation of epitaxial reactors for various practical reasons. The fundamental problem is that the emissivity of the top surface of the wafer is changing during the growth, especially when patterned wafers are deposited of

20   course. The radiation energy picked up by the pyrometer can only be translated into a temperature when the emissivity of the radiating subject is known. Consequently, the pyrometer reading of the radiating top surface of a wafer which emissivity is changing cannot be converted into a temperature

unless the emissivity is known, which is not the case in this arrangement.

Other difficulties, less fundamental but still
5 problematic, are that the pyrometer (1) tends to pick up scattered radiation from heating lamps and (2) quartz process tubes tend to get a thin coating during the deposition. Both of these effects tend to disturb an accurate temperature reading. As should be appreciated, measuring the susceptor
10 temperature in contrast to measuring the wafer temperature, by means of a pyrometer is possible but less than ideal and sensitive to drift.

One embodiment of the present invention is directed to
15 circumventing these difficulties and at the same time solving the problem of the varying wafer temperature. This is accomplished by inserting an optical fiber in a susceptor underneath a wafer in such a way that it receives (monitors) radiation from the backside of the wafer.
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It is noted that an optical fiber inserted in a susceptor may be used in e.g. sputtering and Reactive Ion Etch (RIE) equipment. The purpose of the optical fibers in this case, however, is wafer temperature measurement for
25 which the backside emissivity has to be known. In addition,

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optical temperature measurements, using pyrometers and/or

optical fibers are common in Rapid Thermal Processing (RTP)

equipment. But again in this case, this arrangement only

considers true wafer temperature measurements for which the

5   emissivity of the wafer has to be known.

The optical fiber is to be coupled to a measuring

device. Such measuring devices are well known in the art and

are not described in detail herein. A section from the

10   spectrum for which the wafer is opaque is filtered (band-pass

filter). The optical signal is then converted into an

electrical signal using a transducer.

To maintain a constant wafer temperature, the electrical

15   signal should be kept constant during the deposition cycle.

This is easily achieved by a dedicated control system. The

backside of the wafer may or may not be coated. The only

requirement is that the optical signal is kept constant from

the start of deposition.

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It is noted that the conventional susceptor temperature

measurement system (i.e., element 12 in Fig.1 and elements

24, 28 and 27 in Fig. 2) described above is not modified. It

is also noted that the emissivity of the backside of the

25   wafer does not play a role in this arrangement.

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In another embodiment, one or more optical fibers may be inserted into the susceptor. In this arrangement, one optical fiber monitors a center of the wafer and a second

5   optical fiber monitors an edge of the wafer. By keeping both optical signals constant from the onset of the deposition, the center to edge variations can also be suppressed. It is noted that the emissivity of the wafer backside at the center and at the edge of the wafer does not need to be the same.

10   Inserting additional optical fibers is also possible, but the improvement in performance should be balanced with the increased complexity of the measure/control system.

Those skilled in the art will also realize that the

15   solution to the wafer temperature varying during the deposition cycle, as described here, can also be used to decrease temperature differences that exist in the conventional (epitaxial) reactors between wafers with different patterns or different thickness of the field oxide

20   or nitride.

Since the conventional temperature measurement system (described above) has not been modified, it can be used to in conjunction with various embodiments of the present invention

25   to calibrate the wafer temperature. The procedure is as

follows: a wafer is heated to a deposition temperature at a
first pressure (e.g., an atmospheric pressure). In this
configuration, the thermal coupling between the wafer and the
susceptor is good and the temperature difference between

5   wafer and susceptor is small. The signal levels from the
optical sensors are registered and during the subsequent
deposition cycle at reduced pressure the temperature has to
be controlled in such a way that the signals of the optical
sensors are substantially restored to the registered value.

10   This procedure calibrates the wafer temperature regardless of
the pattern and will result in substantial savings in setting
up the reactor for wafers with different masks and different
thickness of dielectric.

15   Figs. 3a, 3b and 3c are block diagrams of a susceptor 30
in accordance with a preferred embodiment of the invention.
The susceptor 30 consists of two parts: a rotating inner part
31 and a stationary outer part 32 as shown in Fig. 3a. The
rotating inner part 31 holds a wafer 33 in a pocket 34. It

20   is noted that this block diagram shows a complicated case,
i.e., an arrangement that uses thermocouples 24 and 28 for
the temperature measurement. Simpler arrangements may also be
used for the susceptor 30, e.g., without the thermocouples 24
and/or 28 or with only one optical fiber.

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As shown in Fig. 3b, two holes 35 and 36 are drilled through the susceptor 30. One hole 36 is located near the center of the susceptor 30 and the other hole 35 is located near the edge of the wafer 33. Optical fibers 37 and 38 are

5   inserted in the respective holes 35 and 36 so as to pick up the radiation emitted by the backside of the wafer 33 (Fig. 3c). The optical fibers 37 and 38 can, for example, be made of sapphire (Al_2O_3) when very high temperatures are used during the process or quartz (SiO_2) when the temperatures are

10   in the moderate range. The optical fibers 37 and 38 may also be integrated in the (quartz) structure that supports the susceptor 30 (not drawn).

The optical fibers 37 and 38 are coupled to a measuring

15   device 39. A section from the spectrum for which the wafer is opaque (band-pass filter) is filtered. The optical signals are then converted into an electrical signal using a transducer 40, which provides a feedback control signal. A control system 43 receives the feedback control signal and

20   maintains, for example, a constant wafer temperature during a deposition cycle in accordance with the feedback control signal.

The susceptor 30 rotation complicates the coupling of

25   the optical signal to the measuring device 39. Rather than

transforming the optical signals from the optical fibers 37
and 38 into electrical signals (e.g., before transmission
over sliding contacts), as is done with the thermocouple 24
signal, it is preferable to optically couple the rotating
5   optical fibers 37 and 38 to a stationary monitoring device
41. During one susceptor 30 revolution, each of the optical
fibers 37 and 38 transmit optical signals during a short
period of the rotation cycle to the monitoring device 41 when
passing by, via an optical multiplexer 42. This allows for
10   the number of components/parts of the overall system to be
minimized and also allows both signals from the optical
fibers 37 and 38 to follow the same optical and electrical
path, which reduces the influence of drift in the signal-
processing path.

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    The present invention has been described with respect to
particular illustrative embodiments. It is to be understood
that the invention is not limited to the above-described
embodiments and modifications thereto, and that various
20   changes and modifications may be made by those of ordinary
skill in the art without departing from the spirit and scope
of the appended claims.